Uncertainty Estimation for Performance Evaluation of a Confocal Microscope as Metrology Equipment

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Abstract: Both in industry and research, the quality control of micrometric manufactured parts is based on the measurement of parameters whose traceability is sometimes difficult to guarantee. In some of these parts, the confocal microscopy shows great aptitudes to characterize a measurand qualitatively and quantitatively. The confocal microscopy allows the acquisition of 2D and 3D images that are easily manipulated. Nowadays, this equipment is manufactured by many different brands, each of them claiming a resolution probably not in accord to their real performance. The Laser Center (Technical University of Madrid) has a confocal microscope to verify the dimensions of the micro mechanizing in their own research projects. The present study pretends to confirm that the magnitudes obtained are true and reliable. To achieve this, a methodology for confocal microscope calibration is proposed, as well as an experimental phase for dimensionally valuing the equipment by 4 different standard positions, with its seven magnifications and the six objective lenses that the equipment currently has, in the x–y and z axis. From the results the uncertainty will be estimated along with an effect analysis of the different magnifications in each of the objective lenses.

Keywords: Metrology; Confocal microscopy; Uncertainty; Traceability

1. Introduction

Today, the manufacturing companies must be prepared to meet international standards, which include competence to demonstrate the validity of their measurements by estimating its uncertainty [1]. The necessity for manufacturing micrometric parts is a requirement in some industrial and research areas; as technology advances and develops the tools to verify their magnitudes. The microscope as an equipment for quantitative measurement has had to overcome many different obstacles to be considered metrology equipment; an example of this could be its former use as a simple form, or even color, "viewer" (e.g. biology applications). Therefore, to give credibility to its longitudinal measurements it was necessary to visualize reference materials and study the optical effects that could affect its dimensional characterization (aberration, focus, etc.).

Confocal microscopy has its origins in the observation of tiny living beings (microbiology). The simple idea of restraining the specimen illumination to a single point (or series of points) and scan it to produce a complete image, as well as inserting a slit in the optical system to physically prevent the light emanated from the upper and lower planes, contributed to obtaining a better image [2]. This allows confocal microscopy to be a response to the industry necessity for measurement of complex parameters [3] in quality control.

At the Technical University of Madrid, in the Laser Center, micro-mechanized processes, as the one shown in Fig. 1, take place. It is possible to observe a micro-canal whose width needs to be determined by the application of the technique being discussed. To achieve this, it is enough to use the software that comes with the equipment and

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obtain the desired magnitude. Micrometric measurements demand improvement every year but each measurement method has its limitations [4].

Figure 2 shows how the confocal microscope has digitalized an object into a 3D model. It has the great advantage that its information allows to do a sectioning to determine the deformation magnitudes.

Some authors (Takamasu [5]) believe that certain factors must be taken into account when planning a micrometric measurement (3D) such as:

(i) The object's form in 3D.
(ii) Complex workpiece profile.
(iii) And environmental conditions.

In this study, at first an analysis in 2D (x–y) is performed and subsequently used for a 3D analysis by introducing the z axis.

The confocal microscope has the versatility and the capacity to perform length measurements. The success has been so, that some brands manufacture this kind of microscopes specifically to obtain length dimensions. Still, there is doubt if it is possible to guarantee the measurement reliability and calculate its uncertainty. The measurement traceability remains an important factor for quality systems, even when, generally speaking, they are not sufficiently guaranteed [6]. Therefore ensuring the measurements traceability becomes a key factor to assess their performance [7].

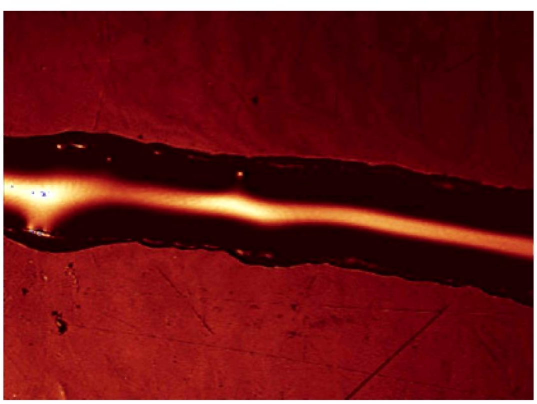


Fig. 1 Aluminum boring

1.1. Equipment Characteristics

The equipment used for this work is described below:

Confocal Microscope (CM), Leica brand, ICM 1000 and model DML, serial number 20002000003, ID CL-EQ- MC-01. Each objective lens has 7 magnifications: 1×, 2×, 3×, 4×, 5×, 6× and 8× [8]. The objective lenses to be evaluated are: 5×/0.12–10×/0.25–20×/0.40–50×/0.50–50×/0.75 and 100×/0.9.

2. Calibration Procedure

2.1. x–y Axes

To start the x and y axes calibration, it is important to understand the uncertainty quantification process for the experiments. The test setup is described in Table 1:

First, it is necessary to identify the measuring range where the evaluation is going to take place, in other words, the boundaries for the microscope's processed image. Figure 3 is an AutoCAD simulation and Fig. 4 is the image obtained. In this case, the measuring range is 250 mm long 200× mm high, using the glass trace standard and working with the 5× objective lens at magnification 8. The linear standards are used for many purposes; in general they are of different shapes with different ranges and materials [9].

(i) Next, the objective lens must be selected and the magnification to be applied to the test must be considered. Magnifications range from No. 1–8, except No. 7. In Fig. 4, the same measuring rage can be obtained with the 10× objective lens at magnification No. 4 or with the 20× objective lens at magnification No. 2.

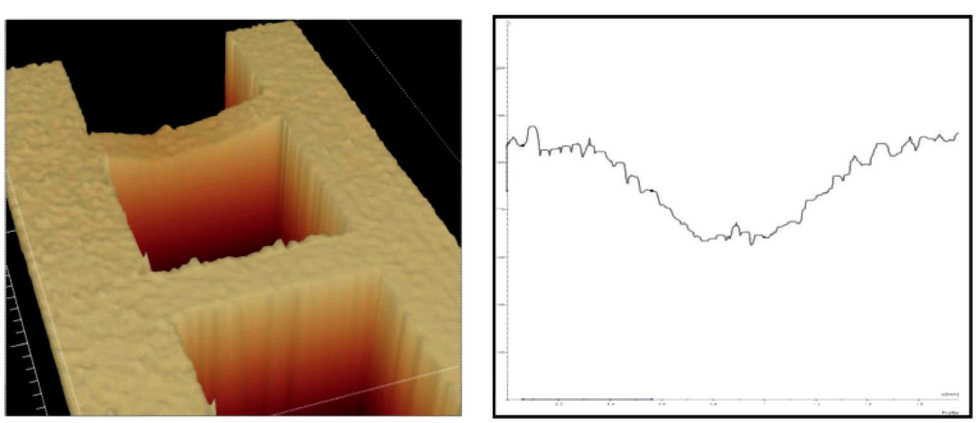


Fig. 2 3D image obtained from the confocal microscope

Table 1 Test characteristics to execute the calibration (x–y axes)

Measurement field (μm)			Objective 5x	10x	20x	50x	50x	100x	Measurement field and characteristics of the standard											
			Numerical aperture 0.12	0.25	0.4	0.5	0.75	0.9	x (μm)	Standard (μm)	No. Points	Interval (μ m)	y (μm)	Standard (μm)	No. Points	Interval (μ m)	45°-135° (μm)	Standard (μm)	No. Points	Interval (μ m)
			Zoom																	
1	2000	1600	1						1000	10	10	100	1000	10	10	100	1000	10	10	100
2	1000	800	2	1					900	10	10	90	700	10	10	70	1000	10	10	100
3	666.7	533.3	3						600	10	10	60	500	10	10	50	600	10	10	60
4	500	400	4	2	1				400	10	10	40	300	10	10	30	400	10	10	40
5	400	320	5						300	10	10	30	300	10	10	30	300	10	10	30
6	333.3	266.7	6	3					300	10	10	30	200	10	10	20	200	10	10	20
7	250	200	8	4	2				200	10	10	20	150	10	15	10	150	10	15	10
8	200	160		5		1	1		150	10	15	10	150	10	15	10	150	10	15	10
9	166.7	133.3		6	3				150	10	15	10	100	10	10	10	100	10	10	10
10	125	100		8	4				100	10	10	10	90	10	9	10	90	10	9	10
11	100	80			5	2	2	1	90	3	10	9	60	3	10	6	60	3	10	6
12	83.3	66.6			6				60	3	10	6	60	3	10	6	60	3	10	6
13	63.3	50			8				50	5	10	5	45	5	9	5	45	5	9	5
14	66.7	53.3				3	3		50	5	10	5	50	5	10	5	50	5	10	5
15	50	40				4	4	2	45	3	15	3	30	3	10	3	30	3	10	3
16	40	32				5	5		36	1.8	10	3.6	27	1.8	15	1.8	27	1.8	15	1.8
17	33.3	26.7				6	6	3	27	1.8	15	1.8	21.6	1.8	12	1.8	21.6	1.8	12	1.8
18	25	20				8	8	4	18	1.8	10	1.8	18	1.8	10	1.8	18	1.8	10	1.8
19	20	16						5	18	1.8	10	1.8	14.4	1.8	8	1.8	14.4	1.8	8	1.8
20	16.7	13.3						6	14.4	1.8	8	1.8	10.8	1.8	6	1.8	10.8	1.8	6	1.8
21	12.5	10						8	9	1.8	5	1.8	7.2	1.8	4	1.8	9	1.8	5	1.8

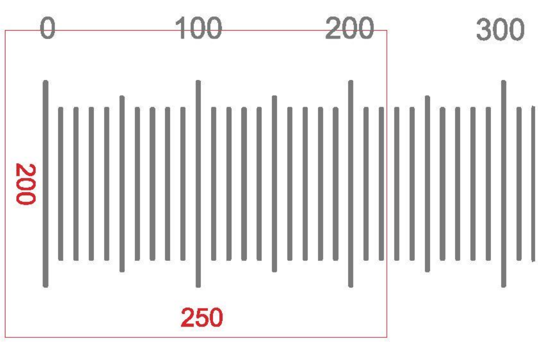


Fig. 3 AutoCAD simulation of the measuring range

(ii) Now it is necessary to identify the standard characteristics (Table 2; Figs. 5, 6).

(iii) Based on the measuring range to be evaluated, the structure of the standard will be adapted along the boundaries of the processed image. The largest possible measuring range will be used. In Table 1, the columns are divided in 4 sections, each to be associated with the standard range on the x and y axes in the 45° and 135° directions respectively.

(iv) 4 positions are to be used, namely P_1, P_2, P_3 and P_4 as shown in Fig. 7. In Fig. 8 an example is shown.
In the column labeled standard, in Table 2, the nominal value of the reference material is defined, depending on the characteristics there described.

(v) Next, the number of points in which the measuring range to be evaluated is going to be divided is specified. A total of 10 repetitions per point are to be made (Figs. 9, 10).

(vi) Finally, the interval is the distance between two adjacent calibration points (Figs. 9, 10).

Each repetition will determine its magnitude with respect to a reference line, being as perpendicular to this line as possible. Therefore, a quantity of values will be

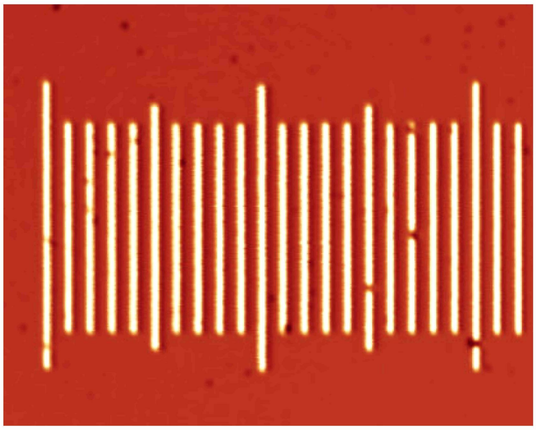


Fig. 4 Processed image of the measuring range

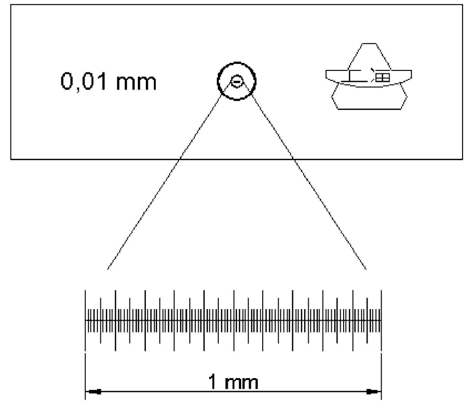


Fig. 5 Glass trace pattern

Table 2 Characteristics of the used standard (x–y axes)

Standard (nominal value) µm	Standard description
10	Glass trace pattern, LMM brand and labeled D071/07. 1 mm measuring range and 10 µm scale division (Fig. 5).
5 3 1.8	Topographic surface standard model STS2-440P, with 1.8, 3 and 5 µm nominal values (Fig. 6).

generated depending on the calibration point number to be evaluated as described in Table 1. The reference line may be formed by two points (as in the glass standard case, Fig. 9) or by ten,—with the help of a lineal regression that will be considered the reference line—(topographic surface standard, Fig. 10).

2.2. z Axis

The standard used for the z-axis is described next (Table 3; Fig. 11):

The standard value used for height difference will be 1.8 µm. Table 4 shows the experiment setup, and Table 3 describes the objectives; with their numerical aperture as well as the minimum measurement interval for the processed images.

Figure 12 obtained with the help of a Confocal Microscope, shows two planes whose height difference is to be determined.

There will be 10 measurements performed along the step (Fig. 13) at 4 different positions (Fig. 7), yielding a total of 40 measurements. Each line segment corresponds to the place where the height difference will be estimated (see also Fig. 14).

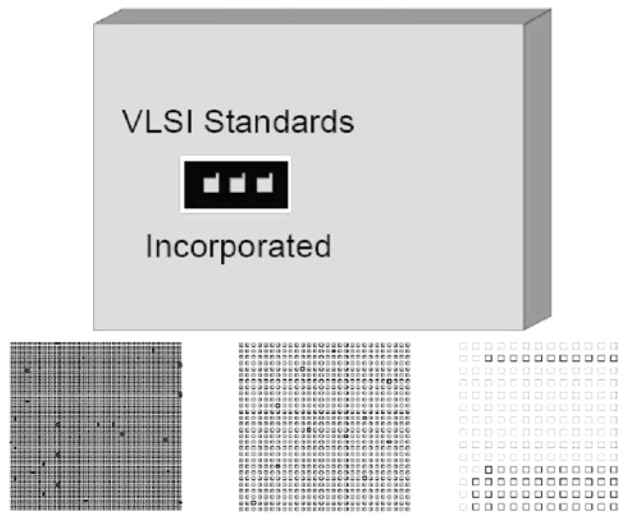


Fig. 6 Topographic surface standard

Once the segments obtained, a figure is generated (Fig. 14) with a line touching both heights in a place where the magnitudes are stable.

3. Results

3.1. x–y Axes

The experimental phase covers the image procurement by using the confocal microscope and the described standards (Fig. 15) so that the equipment could be evaluated dimensionally, by 4 standard different positions, with the 7 magnifications and the 6 objective lenses that the microscope currently has, in the x and y axes (plane), with a total of 168 processed images.

Figure 16 shows the magnitude determination done using the Leica Lite software where the 10 points used to determine the reference line (using a lineal regression) can be appreciated at the left. All of the distances from the reference line to the crosses marked were measured.

3.2. Uncertainty Estimation

Next, the uncertainty estimation, by the combination of the contributions considered, is performed as follows [6, 10]:

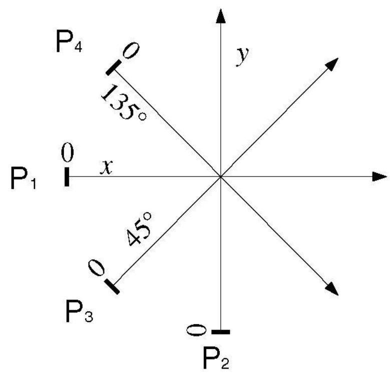


Fig. 7 Standard's measuring positions

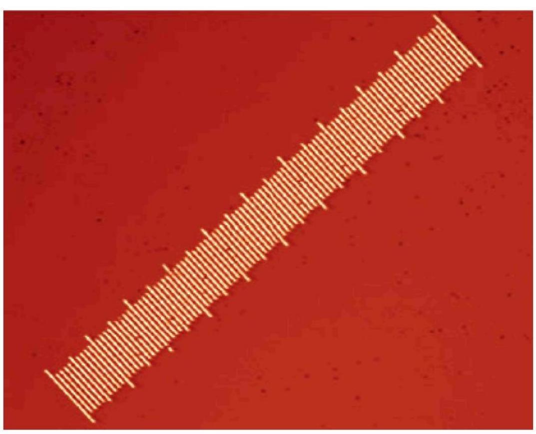


Fig. 8 Example of the standard's position No. 3

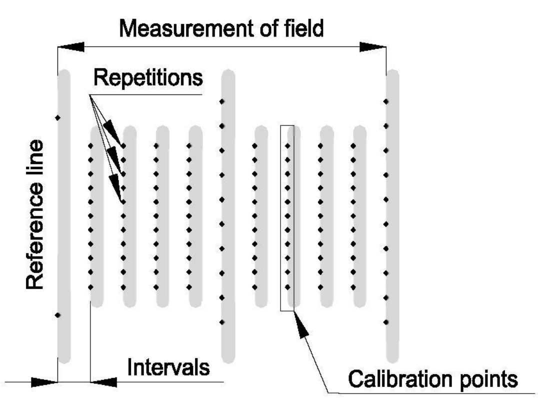


Fig. 9 Total of points to determine in the (10 μm) glass trace standard

u_{pi} is the standard's uncertainty (standard certified value), u_{ci} is the repeatability, u_{inei} is the uncertainty due to standard's instability, u_i is the uncertainty due to temperature differences, u_E is the uncertainty due to instrument resolution

For the expanded uncertainty case it is considered:

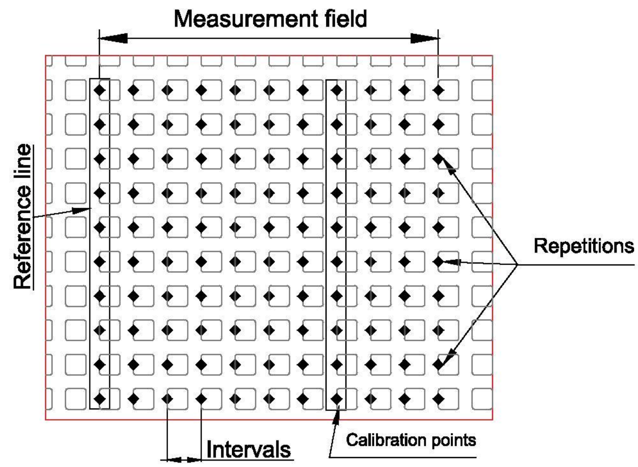


Fig. 10 Total of points to determine in the (1.8, 3 and 5 μm) cell standard

Table 3 Calibration standard for the z-axis

Standard (nominal value)	Standard description
1.8 μm	Surface Topography Standard model: STS2-440P, with nominal values of 1.8, 3 and 5 μm. From these values, the 1.8 μm height difference (step height) will be used for uncertainty estimation purposes throughout this work (Fig. 11).

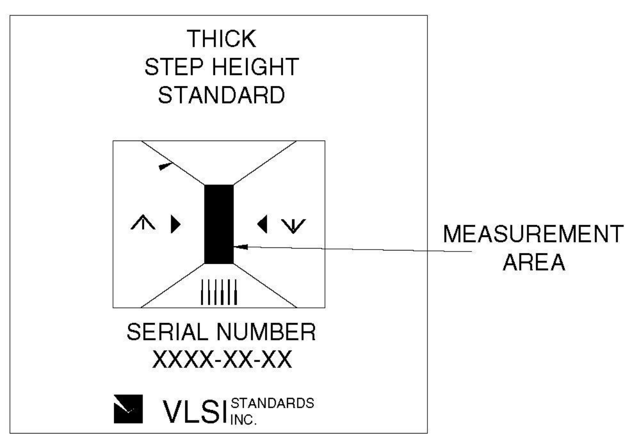


Fig. 11 Surface topography standard

Table 4 Characteristics of the calibration trials (z-axis)

Measurement field (µm)			Objective: 5x	10x	20x	50x	50x	100x	Z: Standard (µm)	No. Points
			Numerical aperture: 0.12	0.25	0.4	0.5	0.75	0.9		
			Zoom							
1	2000	1600	1						1,8	10
2	1000	800	2	1					1,8	10
3	666.7	533.3	3						1,8	10
4	500	400	4	2	1				1,8	10
5	400	320	5						1,8	10
6	333.3	266.7	6	3					1,8	10
7	250	200	8	4	2				1,8	10
8	200	160		5		1	1		1,8	10
9	166.7	133.3		6	3				1,8	10
10	125	100		8	4				1,8	10
11	100	80			5	2	2	1	1,8	10
12	83.3	66.6			6				1,8	10
13	63.3	50			8				1,8	10
14	66.7	53.3				3	3		1,8	10
15	50	40				4	4	2	1,8	10
16	40	32				5	5		1,8	10
17	33.3	26.7				6	6	3	1,8	10
18	25	20				8	8	4	1,8	10
19	20	16						5	1,8	10
20	16.7	13.3						6	1,8	10
21	12.5	10						8	1,8	10

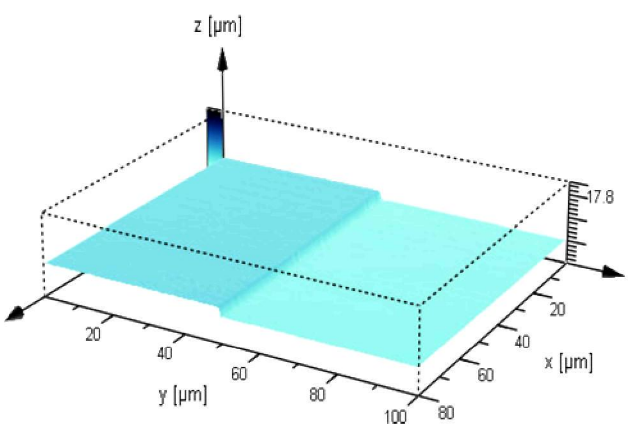


Fig. 12 Height difference of two planes (step height)

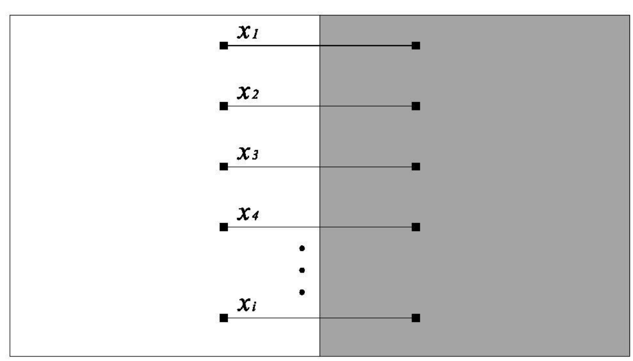


Fig. 13 Magnitude determination on the step height standard

Fig. 14 Graph of the height difference between two planes (*side view*)

Fig. 15 Standards' images obtained by the confocal microscope

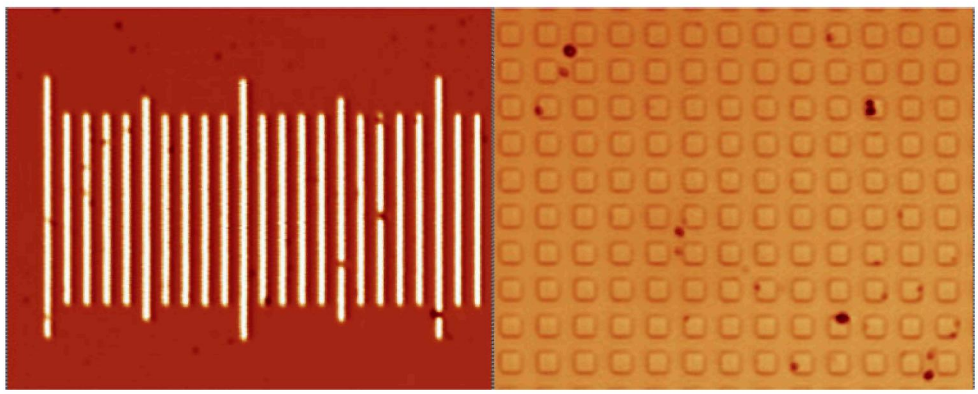
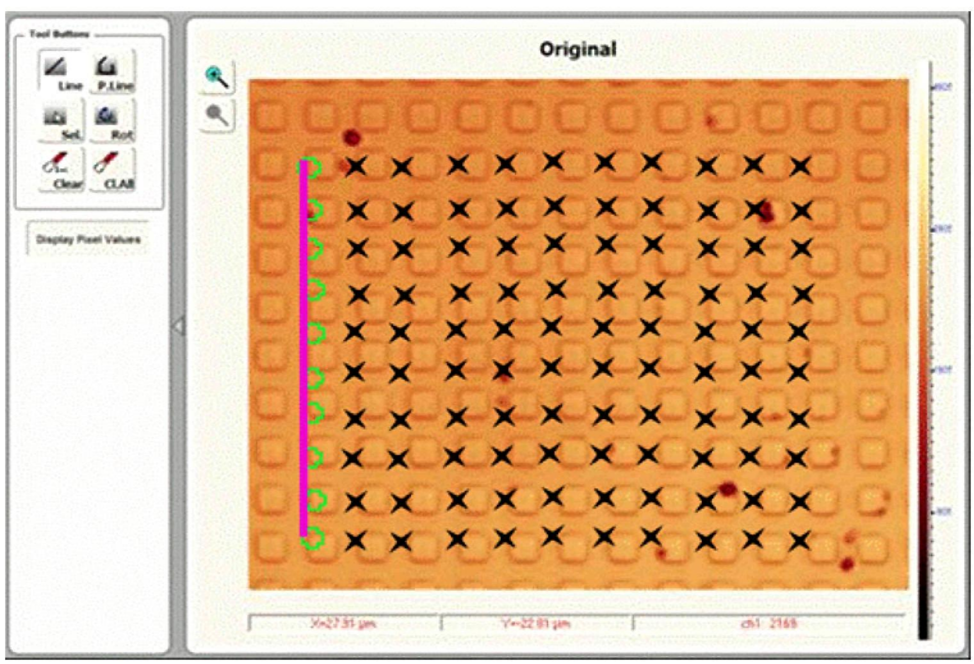


Fig. 16 Standard's image obtained by the confocal microscope



$$U = 2u \tag{2}$$

Considering no correction is made and according to F.2.4.5 of GUM [11], $c_c = 0$ the associated expanded uncertainty is:

$$U(c_c = 0) = \max U(c_{ci}) + \max|c_{ci}| \tag{3}$$

4. Results, Analysis and Discussion

Each graph shows the evaluated calibration interval with its respective uncertainty estimation and a series of lines identified by a label. An example: Z3 P2 min, means that for magnification No. 3 the lowest uncertainty was

Table 5 Estimated uncertainty and its nominal value for 5× objective lens

Z3 P2 min		Z4 P2 min		Z5 P3 min	
50	1.53	30	1.33	30	1.42
100	1.55	60	1.36	60	1.44
150	1.56	90	1.38	90	1.46
200	1.57	120	1.41	120	1.48
250	1.58	150	1.44	150	1.50
300	1.60	180	1.47	180	1.52
350	1.61	210	1.49	210	1.54
400	1.62	240	1.52	240	1.56
450	1.64	270	1.55	270	1.58
500	1.65	300	1.58	300	1.61

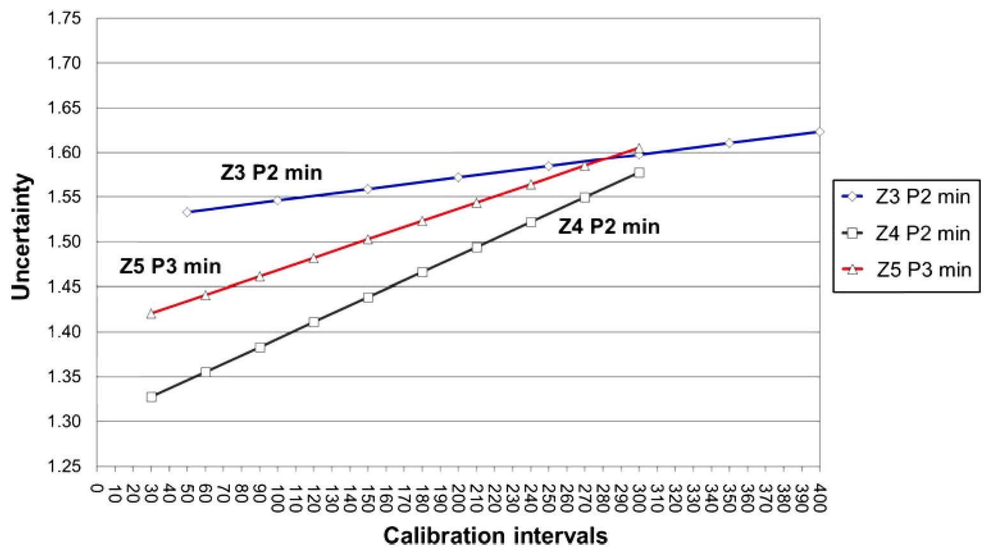


Fig. 17 Uncertainty comparison for magnifications Nos. 2–8, with the ×5 objective lens

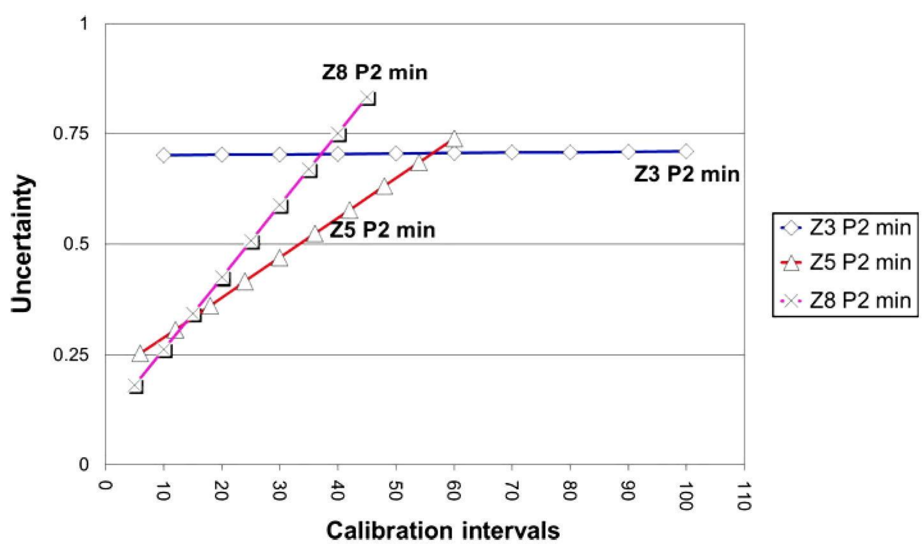


Fig. 18 Uncertainty comparison for magnifications Nos. 2–8, with the ×20 objective lens

Table 6 Estimated uncertainty and its nominal value for the 20× objective lens

Z3 P2 min		Z5 P2 min		Z8 P2 min	
10	0.70	6	0.25	5	0.18
20	0.70	12	0.31	10	0.26
30	0.70	18	0.36	15	0.34
40	0.70	24	0.42	20	0.43
50	0.71	30	0.47	25	0.51
60	0.71	36	0.52	30	0.59
70	0.71	42	0.58	35	0.67
80	0.71	48	0.63	40	0.75
90	0.71	54	0.69	45	0.83
100	0.71	60	0.74		

achieved in position No. 2 for the 5× objective lens (Fig. 17). Evidently, it was expected that by increasing the magnification, the performance would increase as well; therefore the next analysis is made.

4.1. x–y Axes

4.1.1. Uncertainty Estimation Analysis for Different Magnifications but Same Objective Lens

In the results shown, magnification No. 1 is dismissed because its values are considerably greater than the rest. Different magnifications are shown because they can be represented in a graph.

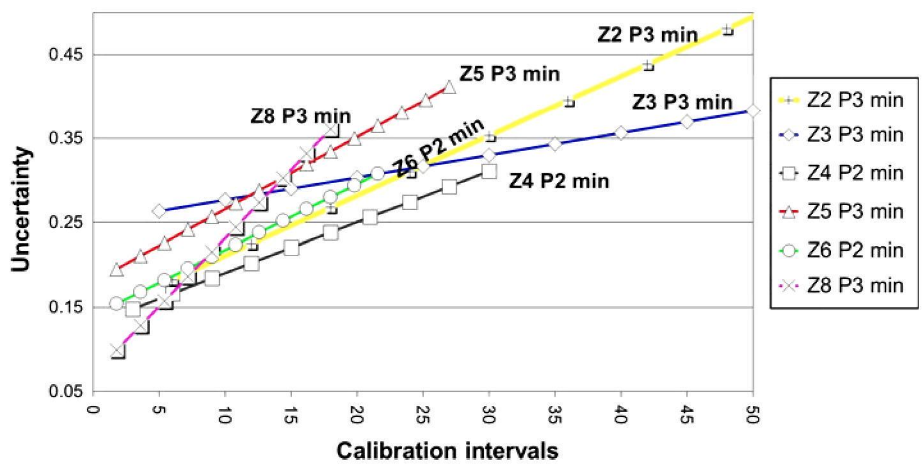


Fig. 19 Uncertainty comparison for magnifications Nos. 2–8, with the ×50 objective lens (0.75)

Table 7 Estimated uncertainty and its nominal value for the 50× objective lens (0.75)

Z2 P3 min		Z3 P3 min		Z4 P2 min		Z5 P3 min		Z6 P2 min		Z8 P3 min	
6	0.18	5	0.26	3	0.15	1.8	0.20	1.8	0.15	1.8	0.10
12	0.23	10	0.28	6	0.17	3.6	0.21	3.6	0.17	3.6	0.13
18	0.27	15	0.29	9	0.18	5.4	0.23	5.4	0.18	5.4	0.16
24	0.31	20	0.30	12	0.20	7.2	0.24	7.2	0.20	7.2	0.19
30	0.35	25	0.32	15	0.22	9	0.26	9	0.21	9	0.22
36	0.40	30	0.33	18	0.24	10.8	0.27	10.8	0.22	10.8	0.24
42	0.44	35	0.34	21	0.26	12.6	0.29	12.6	0.24	12.6	0.27
48	0.48	40	0.36	24	0.27	14.4	0.30	14.4	0.25	14.4	0.30
54	0.52	45	0.37	27	0.29	16.2	0.32	16.2	0.27	16.2	0.33
60	0.57	50	0.38	30	0.31	18	0.33	18	0.28	18	0.36
						19.8	0.35	19.8	0.29		
						21.6	0.37	21.6	0.31		
						23.4	0.38				
						25.2	0.40				
						27	0.41				

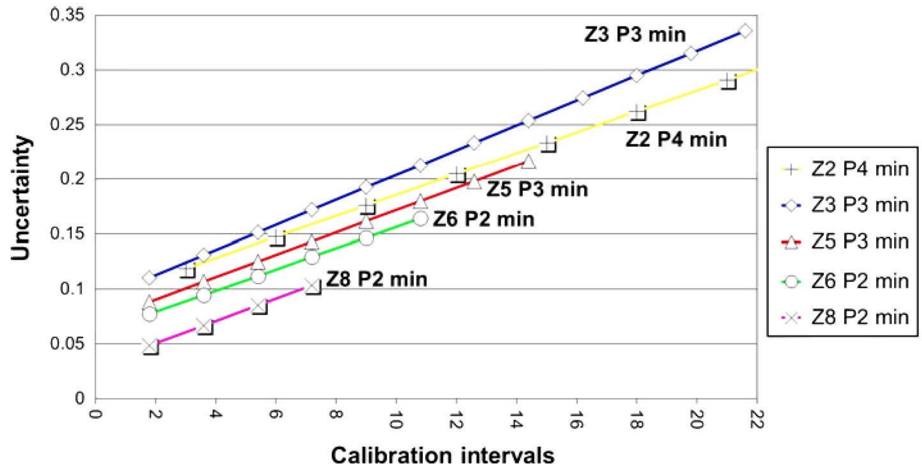


Fig. 20 Uncertainty comparison for magnifications Nos. 2–8, with the $\times 100$ objective lens

Table 8 Estimated uncertainty and its nominal value for the 100× objective lens

Z2 P4 min		Z3 P3 min		Z4 P2 min	
3	0.12	1.8	0.11	1.8	0.11
6	0.15	3.6	0.13	3.6	0.12
9	0.18	5.4	0.15	5.4	0.14
12	0.20	7.2	0.17	7.2	0.15
15	0.23	9	0.19	9	0.17
18	0.26	10.8	0.21	10.8	0.18
21	0.29	12.6	0.23	12.6	0.20
24	0.32	14.4	0.25	14.4	0.21
27	0.35	16.2	0.27	16.2	0.23
30	0.38	18	0.29	18	0.24
Z5 P3 min		19.8	0.32	Z8 P2 min	
1.8	0.09	21.6	0.34	1.8	0.05
3.6	0.11	Z6 P2 min		3.6	0.07
5.4	0.12	1.8	0.08	5.4	0.09
7.2	0.14	3.6	0.09	7.2	0.10
9	0.16	5.4	0.11		
10.8	0.18	7.2	0.13		
12.6	0.20	9	0.15		
14.4	0.22	10.8	0.16		

4.1.2. *5× Objective Lens, Magnification Nos. 2–8*

The results shown in Fig. 17 are unexpected because in magnification No. 5 it does not respect the condition of lower uncertainty for greater magnification. Therefore it is suggested that, for small values, magnification No. 8 be used in position No. 2 (Z8 P2 min) whenever possible.

The uncertainty estimation results are shown in the next table, where the nominal value and its estimated uncertainty are compared for each corresponding point (Table 5).

Table 9 Uncertainty estimation (μm) for step height measurement with a 5× objective lens with its 7 magnifications and 4 measurement points (P1, P2, P3 and P4)

Uncertainty					
Zoom	P1	P1 U95 (Cci = 0)	Zoom	P2	P2 U95 (Cci = 0)
1	2.54	2.34	1	1.63	1.39
2	2.39	2.22	2	1.66	1.52
3	2.23	1.93	3	1.68	1.48
4	2.07	1.50	4	1.71	1.65
5	1.92	1.48	5	1.74	1.49
6	1.76	1.38	6	1.77	1.65
8	1.45	1.36	8	1.83	1.60

4.1.3. *20× Objective Lens, Magnification Nos. 2–8*

Magnification No. 5 in position No. 2 (Fig. 18; Table 6) has the overall least uncertainty, but its maximum least uncertainty is higher than those for other magnifications. Therefore, even though it has the lowest uncertainty, the most recommended action would be to use magnification No. 8 in position No. 2. This is the most stable objective lens with better metrological characteristics.

4.1.4. *50× Objective Lens (0.75), Magnification Nos. 2–8*

It is observed in Fig. 19 and Table 7 that the beneficial effect obtained in other objective lenses by increasing the magnification is no longer present. In this objective lens, it is important to consider the uncertainties produced in every magnification, whose results are not as evident. Therefore, and based in these observations, the use of magnification No. 4 in position No. 2 (Z4 P2 min) is recommended.

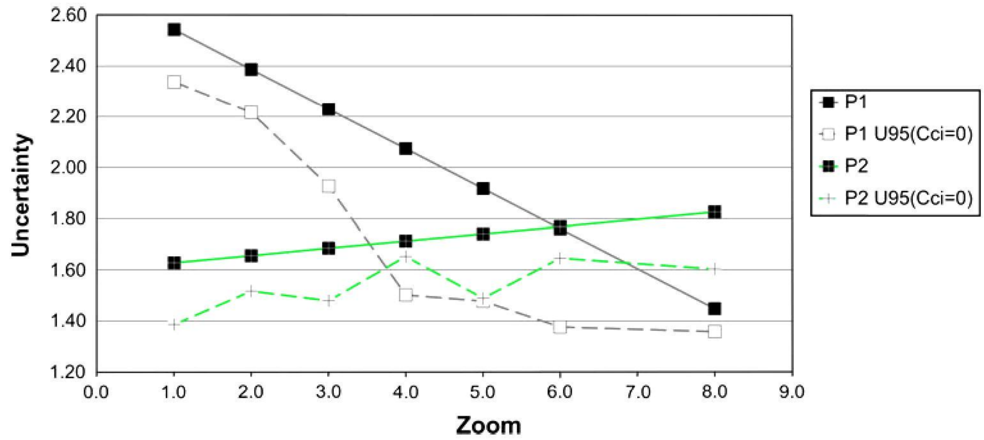


Fig. 21 Uncertainty comparison, for step height measurement with ×5 objective lens

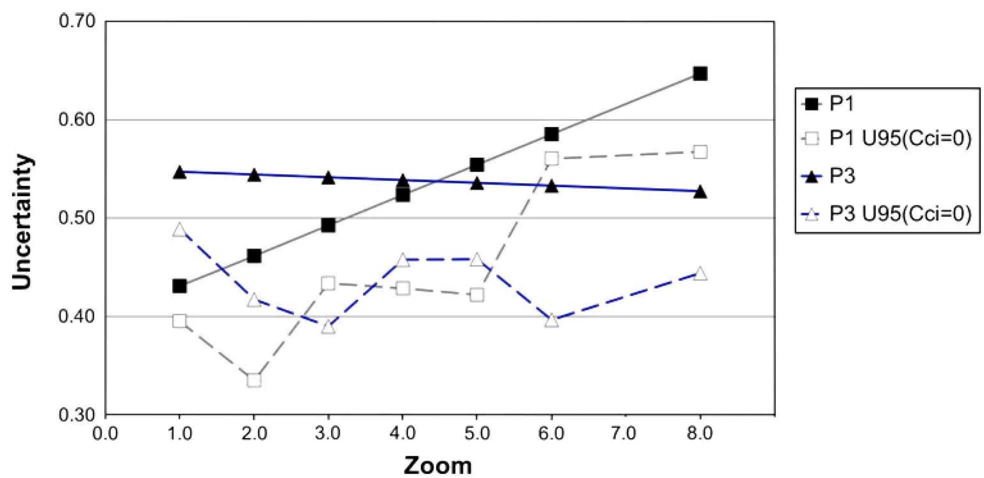


Fig. 22 Uncertainty comparison, for step height measurement with ×10 objective lens

4.1.5. 100× Objective Lens, Magnification Nos. 2–8

It can de deduced from Fig. 20 and Table 8 that, by increasing the magnification, the uncertainty values decrease (except for Z2 P4 min). Therefore, magnification No. 8 in position No. 2 (Z8 P2 min) has the lowest uncertainty value and is the best choice.

4.2. z Axis

In this section is presented the uncertainty estimation analysis for the height difference (1.8 μm), for a given objective lens at different magnifications

4.2.1. Objective Lens 5×

The tendency of the uncertainty in general is to decrease as the zoom increases (Table 9), therefore it is convenient to use the largest zoom for all four positions even though for magnifications 6 and 8 the results are similar. Position No. 1 yields the overall least uncertainty (with the zoom set to 8), however for zoom 1–3 position No. 2 yields the least uncertainty. Roughly speaking, position No. 2 shows the best performance, without forgetting position No. 1 for zoom 6 and 8 (Fig. 21). From Fig. 21 on, U95(Cci = 0) means confidence level = 95 %, no calibration correction.

Table 10 Uncertainty estimation (μm) for step height measurement with a 10× objective lens with its 7 magnifications at 4 measurement points (P1, P2, P3 and P4)

Uncertainty					
Zoom	P1	P1 U95 (Cci = 0)	Zoom	P3	P3 U95 (Cci = 0)
1	0.43	0.40	i	0.55	0.49
2	0.46	0.33	2	0.54	0.42
3	0.49	0.43	3	0.54	0.39
4	0.52	0.43	4	0.54	0.46
5	0.55	0.42	5	0.54	0.46
6	0.59	0.56	6	0.53	0.40
8	0.65	0.57	8	0.53	0.44

Fig. 23 Uncertainty comparison, for step height measurement with 50× 0.75 objective lens

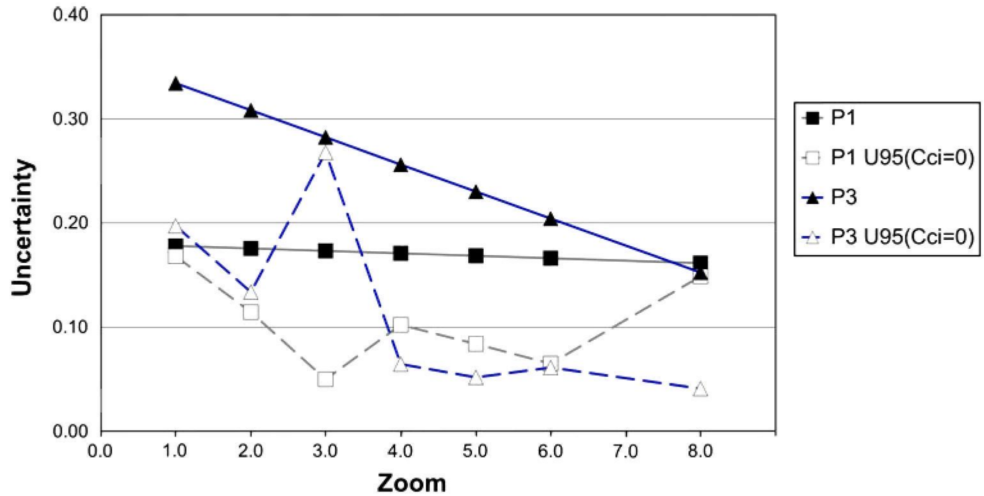


Table 11 Uncertainty estimation (μm) for step height measurement with a 50× 0.75 objective lens with its 7 magnifications at 4 measurement points (P1, P2, P3 and P4)

Incertidumbre											
Zoom	P1	P1 U95 (Cci = 0)	Zoom	P2	P2 U95 (Cci = 0)	Zoom	P3	P3 U95 (Cci = 0)	Zoom	P4	P4 U95 (Cci = 0)
1	0.18	0.17	1	0.30	0.29	1	0.33	0.20	1	0.43	0.31
2	0.18	0.11	2	0.29	0.14	2	0.31	0.13	2	0.40	0.38
3	0.17	0.05	3	0.27	0.17	3	0.28	0.27	3	0.36	0.32
4	0.17	0.10	4	0.25	0.15	4	0.26	0.06	4	0.33	0.18
5	0.17	0.08	5	0.24	0.14	5	0.23	0.05	5	0.29	0.14
6	0.17	0.07	6	0.22	0.21	6	0.20	0.06	6	0.26	0.23
8	0.16	0.15	8	0.19	0.09	8	0.15	0.04	8	0.19	0.10

Fig. 24 Uncertainty comparison, for step height measurement with ×100 objective lens

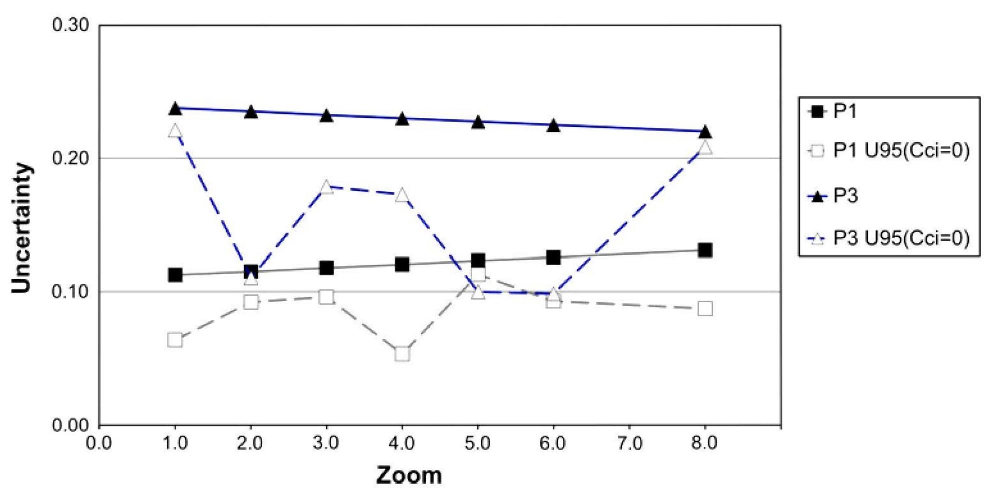


Table 12 Uncertainty estimation (μm) for step height measurement with a 100× objective lens with its 7 magnifications at 4 measurement points (P1, P2, P3 and P4)

Uncertainty						
Zoom	P1	P1 U95 (Cci = 0)	Zoom	P3	P3 U95 (Cci = 0)	Zoom
1	0.11	0.06	1	0.24	0.22	1
2	0.12	0.09	2	0.23	0.11	2
3	0.12	0.10	3	0.23	0.18	3
4	0.12	0.05	4	0.23	0.17	4
5	0.12	0.11	5	0.23	0.10	5
6	0.13	0.09	6	0.22	0.10	6
8	0.13	0.09	8	0.22	0.21	8

4.2.2. Objective Lens 10×

In Fig. 22 are shown the uncertainty values obtained for the experiment using a 10× objective lens. It can be seen how the uncertainty values lower and compact themselves as the zoom increases. Position No. 3 stands out yielding low uncertainties at different zoom values, but position No. 1, under certain conditions, yield even lower uncertainties. Hence, either of them could be used indistinctively, except in the case that the experiment to perform required the largest magnifications (6 and 8). Magnification No. 3 has small uncertainties (Table 10).

4.2.3. Objective Lens 50× 0.75

Figure 23 shows the results for step height measurement with a 50× 0.75 objective lens. It can be seen that the lines describing the uncertainty behavior have big negative slopes and thus uncertainty decreases rapidly as the magnification increase. It can also be seen that position P1 for zoom 1– 6 yields low uncertainties (Table 11).

4.2.4. Objective Lens 100×

Figure 24 shows the results for step height measurement with a 100× objective lens. It can be seen that magnification No. 6 present good results at all positions; moreover, the uncertainty estimations are very close to each other. Position No. 1 yields low uncertainties at all magnifications; therefore, it is suggested for operation (see Table 12).

5. Conclusions

In this work it was developed a calibration procedure to determine the uncertainty of the confocal microscope. This procedure has two stages: first a dimensional characterization is carried out and then the uncertainty estimation is performed.

Regarding traceability, the calibration was carried out with the contributions traced to primary standards. In Spain, some of the standards used are traced to the CEM but the smaller standards are usually traced to laboratories and manufacturers in other countries.

The results obtained show that the confocal microscopes can be used successfully in metrology due to its versatility and good performance.

On the calibration results of the x–y and z axes we can find some effects that stand out, produced by some of their most important functionality parameters, like:

(i) Different magnifications for each objective lens have a direct influence on uncertainties. In general the thumb rule is: higher amplification yields lower uncertainty.
(ii) The standard's position has shown a significant effect on uncertainty; this could be related to the equipment's scan method. Therefore, the calibration procedure and the measurement process should take into account the position of the object to measure.
(iii) Different combinations of objective lens and magnifications can yield the same measuring field but different performance. This (along with point 1) suggests that, for a given measuring field, the highest magnification should be preferred.
(iv) For height differences determination it was found that the confocal microscope did not complied the resolution established by the manufacturer. Thus, when a new product is offered, it is necessary to carry out a study to determine its real capacities and characteristics.

For the z-axis calibration the following was observed:

Confocal microscopy provides a competitive alternative for step height measurement with respect to other techniques. Confocal microscopy achieves uncertainties as low as 0.04 μm while conventional rugosimeters achieve uncertainties of about 0.1 μm, vision measurement systems yield uncertainties of about 2 μm and atomic force microscopy yield uncertainties of about 0.09 μm.

Acknowledgments The authors are indebted to the Laser Center (Technical University of Madrid) for the support offered in the execution and analysis of the experiments. This work was funded by the Research Support Fund (FAI) of the University of San Luis Potosí and the PROMEP program.

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